DSN TECHNOLOGY AND SCIENCE PROGRAM NEWS
JUNE 1996
ISSUE 5

IN THIS ISSUE

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Starting with this issue, the scope of this newsletter is expanded to include Deep Space Network (DSN) science topics. Science and technology have always been closely coupled in the DSN. The radio telescopes of the DSN constitute a world-class instrument for radio astronomy, planetary radar, and radio science, and many of the DSN's technology developments directly benefit these endeavors. At the same time, DSN science users often lead the way in proving new techniques that subsequently become core operational DSN capabilities.

This issue includes three technology articles covering media calibrations for the Cassini mission radio science experiment, a cooperative international laser demonstration, and charge-coupled-device (CCD) instrument development. In addition, there is a science article on star-formation observations.

Larry Teitelbaum describes the results of an experiment that demonstrates the ability of water vapor radiometers (WVRs) to measure line-of-sight wet-path delay fluctuations and reduce their impact on very-long-baseline-interferometry (VLBI) observations. The Cassini mission radio science experiment will use Ka-band frequencies to minimize plasma effects along the propagation path, leaving the troposphere as the dominant media-error contribution. WVRs will be a key component of the calibration system required to meet the ambitious radio science goals of that mission.

Keith Wilson describes the two-way optical communications Ground-to-Orbiter Lasercomm Demonstration (GOLD). This is a joint Communications Research Laboratory (CRL), Japan/Jet Propulsion Laboratory (JPL) experiment using the Japanese Engineering Test Satellite (ETS-VI) and JPL's Table Mountain Facility (TMF). These optical demonstrations are early steps toward the anticipated development of operational Earth orbiters and deep-

CONTINUED ON PAGE 11

MEDIA CALIBRATION FOR CASSINI RADIO SCIENCE

LARRY TEITELBAUM

Motivation for Troposphere Calibration

Cassini will be the first planetary mission to use a Ka-band (32-/34-GHz) two-way link for radio science experiments. One of the most important benefits of such a high link frequency for radio science experiments is the greatly reduced noise from plasma irregularities in the interplanetary medium. The magnitude of microwave delay fluctuations from plasma is inversely proportional to the microwave frequency squared, so these delay fluctuations will be a factor of approximately 15 smaller than those with an X-band (8 GHz) link. The Cassini Gravitational Wave Search Experiment (GWE) hopes to achieve a factor-of-10-better sensitivity to gravitational waves than that in any previous spacecraft experiment.

With the much smaller plasma noise level, tropospheric noise will dominate under most conditions. Tropospheric delay fluctuations are independent of link frequency (i.e., they are nondispersive). Unless we can

CONTINUED ON PAGE 2

Calibration continued from page 1

calibrate the tropospheric fluctuations on the round-trip link measurements, we will not be able to take full advantage of the improved accuracy possible with a Ka-band link. In particular, the Cassini GWE has identified tropospheric delay fluctuations as one of the dominant error sources limiting gravitational wave detection. The goal for the Cassini Troposphere Calibration Subsystem—an Allan Standard Deviation better than 4×10^{-16} (s/s) on time scales from 1000 to 10000 s—requires an order-of-magnitude better performance than has been demonstrated by current troposphere calibration instrumentation. Thus, high-precision troposphere calibration is an enabling technology for the Cassini GWE. In addition, the Cassini Solar Conjunction Experiment and gravity field measurements of Saturn and its satellites will benefit from troposphere calibration.

Tropospheric Fluctuations and a Path to Their Calibration

Most (95% or more under most conditions) of the tropospheric delay at microwave frequencies is caused by dry air (molecular nitrogen and oxygen, plus trace gases). However, the distribution of dry air is highly uniform due to pressure equilibrium, and most variations in tropospheric delay on the time scale of a spacecraft tracking pass are due to irregularities in the distribution of water vapor. Water vapor has a much higher refractivity at microwave frequencies than dry air, and its distribution in the troposphere has irregularities on all spatial scales.

Efforts at calibrating tropospheric delay fluctuations along the line of sight between a DSN antenna and a spacecraft have focused on the spectral line of water vapor, which is centered at 22 GHz. The brightness temperature of the troposphere at frequencies near this spectral line provides information on both the amount of water vapor and its contribution to the tropospheric path delay along the line of sight.

Water vapor radiometers (WVRs) measure the atmospheric brightness temperature at one or more frequencies in the vicinity of the 22-GHz water vapor spectral line. Significant development work in WVRs has been done in Division 38 for 20 years, and JPL-built WVRs have been used successfully to measure the average wet delay (i.e., averaged over all sky directions) at a site. The demands of Cassini radio science experiments are much more stringent than those that drive the design of current generation WVRs. Therefore, we have focused on (1) characterizing the true performance of current WVRs, and (2) designing an advanced WVR.

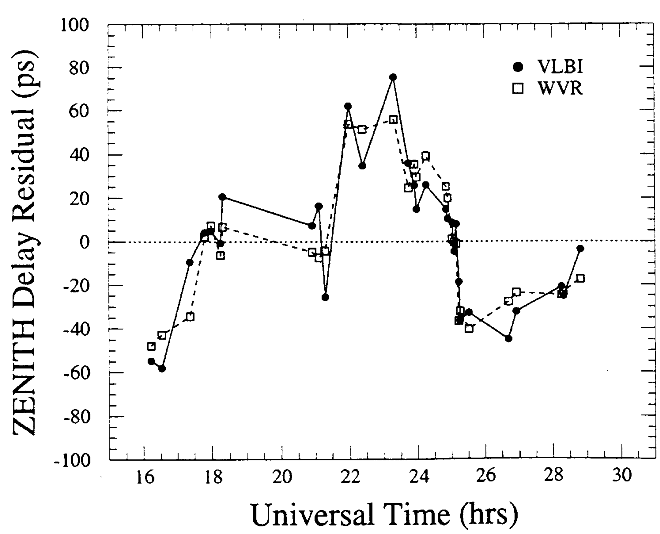

Figure 1. Site-differenced delays vs. Universal Time.

Goldstone VLBI/WVR Tests

In September 1994, we performed an experimental test of WVR calibration capability at Goldstone. Very-long-baseline-interferometry (VLBI) observations of natural radio sources (quasars) were made at DSS 13 and DSS 15. VLBI observations over this 21-km baseline enabled very precise measurements of the delay in arrival time of wave fronts from the radio sources at the two antennas. Dual-frequency S/X-band observations allowed the effects of plasma to be removed, and the delay due to observing geometry could also be accurately subtracted. After estimating three parameters from the data—a station-differenced mean tropospheric zenith path delay, clock epoch, and clock rate—a postfit delay residual was obtained that we believe was due almost

Continued on page 10

GOLD: A Demonstration Of The First Megabit-per-Second Bidirectional Optical Communications at Geosynchronous Range

OPTICAL COMMUNICATIONS

Keith E. Wilson

The National Aeronautics and Space Administration/Jet Propulsion Laboratory (NASA/JPL), the Communications Research Laboratory (CRL), Japan, and the National Aeronautics and Space Development Agency of Japan (NASDA) have demonstrated the first megabit-per-second bidirectional space-to-ground optical link from geostationary ranges. The Ground-to-Orbiter Lasercomm Demonstration (GOLD) was performed between a laser transmitter at JPL's Table Mountain Facility (TMF) in Wrightwood, CA, shown in Figure 1, and the Japanese Engineering Test Satellite (ETS-VI) (1, 2). The satellite is in a three-day-recurrent highly elliptical orbit. The precession of its orbit brings the satellite to apogee approximately fifteen minutes earlier on each pass over TMF. This has allowed us to evaluate both daytime and nighttime optical link performance over the seven-month-long demonstration period.

GOLD is the latest in a series of Telecommunications and Mission Operations Directorate- (TMOD) supported optical communications demonstrations designed to evaluate optical communications. Initially appealing because of its high data rate potential, optical communications is becoming an attractive alternative to radio frequency (RF) for transmitting high volumes of data in the current climate of small spacecraft. Recent studies have shown that an optical telecommunications subsystem can return data volumes of 10 Gbits/day from Mars in a package that consumes less power and is approximately 55% of the mass of either X-band or Ka-band systems (3). GOLD follows just a few years after the Galileo Optical Experiment (GOPEX) in 1992 (4) and the compensated-Earth-Moon-Earth retroreflector laser link (CEMERLL) in 1994 (5). The latter demonstrated propagation of a narrow (0.000086 degree) atmosphere-compensated laser beam to the Apollo 15 lunar retroreflectors. The data from GOLD will be used to improve our current optical-link-performance models.

There were two phases of the GOLD transmissions. Phase-I began in October 30, 1995 and extended through January 13, 1996. These transmissions were performed at night when the satellite could be visually acquired in the night sky. This first phase ended when a two-month-long apogee-eclipse limited the ETS-VI's power generation capability and prevented experiments with the satellite. Phase-II experiments began on March 21, 1996 and are planned to end on May 26, 1996. These include a significant number of daytime experiments, and will evaluate strategies for daytime satellite acquisition.

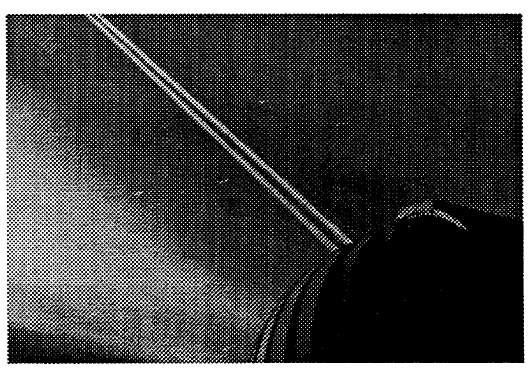

Figure 1. Dual Argon-Ion laser beams were transmitted from TMF to reduce the intensity fades on the uplink transmission. (Photograph courtesy of C. Edwards.)

CONTINUED ON PAGE 4